Geographies of the Holocaust: Experiments in GIS, QSR and graph representations

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There has been growing recognition that the Holocaust was profoundly spatial. (Charlesworth 2004; Knowles, Cole & Giordano 2014; Cole 2016). From the role played by spatial concepts such as “lebensraum” (literally “living space”) in Nazi ideology and policy (Bassin 1987; Rossler 1989; Clarke, Doel & McDonough 1996; Barnes & Minca 2013; Barnes 2015; Giaccaria & Minca 2016), through the new spaces and places (ghettos, camps) created across occupied Europe (Cole & Smith 1995; Cole 2003; Knowles, Cole & Giordano 2014) to the mass dislocation genocide entailed (Gigliotti 2009; Knowles, Cole & Giordano 2014; Cole 2016), the Holocaust was clearly a geographical event as well as an historical event. Given this, recent scholarship has drawn on a range of spatial concepts and methods. One strand of this work has experimented with the ways that Geographical Information Science and geo-visualisation tools might uncover spatial patterns at a variety of scales ranging from the continental, through the national to the regional and local (Beorn et al 2009; Giordano & Cole 2011; Cole & Giordano 2014; Knowles, Cole & Giordano 2014).

These experiments in using GIS tools have been productive in stimulating new questions and hypotheses (Giordano & Cole 2011; Cole & Giordano 2014; Knowles, Cole & Giordano 2014). However, they have experienced the challenges faced by digital humanists when working with historical and literary sources or data. As Bodenhamer, Corrigan, and Harris (2010) note, compared to the social sciences and the physical sciences, “the humanities pose far greater epistemological and ontological issues” to GIS methods given the complex nature of the sources that lack the precision that GIS demands. The implications of this move beyond epistemology into ethics. Troublingly, GIS tools have so far proven better suited to working with the documents produced by the perpetrators with their chimera of certainty (e.g. the architectural archive from Auschwitz or the lists of ghetto house designated by the local authorities in Budapest) than the post-war testimony of Holocaust survivors (Knowles, Cole & Giordano, 2014). As a result adopting GIS tools has tended to privilege understandings of perpetrator space over victim experiences of genocidal place. In short, to explore the spatiality of victim testimony new methods are necessary (Giordano and Cole 2018; Giordano and Cole 2019 forthcoming; Knowles, Jaskot, Cole & Giordano 2020 forthcoming).

Introduction of two use cases: trajectories and zoom/parthood

There are multiple aspects of the spatial experiences of victims of genocide that can be explored, but two concern us here. Firstly, forced movement is key to many genocides, and in the case of the Holocaust this meant that many - if not all – Jews experienced movement to and through a network of ghettos, transit camps and concentration, labour and death camps. GIS can be used to map these spatio-temporal patterns of movement during the Holocaust when there is enough certainty in the data (Knowles, Cole & Giordano 2014). However, victims' narratives often lack spatial and temporal precision. The result is that even something as seemingly simple as mapping out the trajectories taken by one family through a series of ghettos in the Hungarian capital Budapest in 1944 becomes difficult given that survivor Magda Mezei (Lapidus) struggled to remember the precise addresses that she lived in during this chaotic and traumatic period (USHMM 1990; Giordano & Cole 2019 forthcoming). While she remembered a series of different streets, she struggled to recall which house she was forced to move into within this dispersed ghetto that was created at the scale of individual apartment building (Cole 2003). This points not simply to a failure of memory in survivor narratives, but can in itself be data that reveals the difficulties of orienting self within a rapidly changing geography of dislocation where the certainty of place (and a sense of self in the world) begins to unravel (Pollin-Galay 2020 forthcoming). How to represent the uncertain trajectories of victims in order to enable comparative analysis is a key challenge to digital humanists.

But secondly, a further challenge comes from another aspect of the sources that we draw upon. Oral history interviews with survivors – and in the case of the Holocaust these number into the tens of thousands – are complex narratives that are co-created in an exchange between interviewer and interviewee. As they talk about space and place, interviewees move freely between a variety of scales as they describe events that took place simultaneously at the scale of their gendered body and the European continent, as well as at all scales in between (Cole 2020 forthcoming). Scale operates metaphorically as a set of Russian dolls (Herod 2010), with the body inside the local, inside the regional, inside the national, inside the continental, inside the global. Survivors tend to move in between these scales in narratives that are spatially (and oftentimes also temporally) dynamic rather than fixed. For example, Magda's narrative of ghettoization in Budapest moves between the scale of the room where she and her family lived, the apartment that room was in, the building housing that apartment, the street it was situated on, the district in the city and so on. All are important at different times in different ways and so there is a need for more dynamic "mapping" that enables this zooming in and out across both uncertain (room) and certain (street) places in the narrative (Giordano & Cole 2019 forthcoming). In this short paper, we draw on these two challenges to consider how approaches drawn from the methods of Qualitative Spatial Representation (QSR) might prove useful to digital humanists as they reach the limits of GIS. In particular, we suggest a need to return to first principles and reconsider database design.

Data Representation

In traditional geographic information system and geospatial databases, such as Oracle Spatial (Ying Hu et al. 2012) or PostGIS (Obe and Hsu 2015), spatial information is encoded by assigning each named place a geometric representation. This can be either a point location, which is represented as a coordinate pair denoting latitude and longitude, or more complex geometric features such as a polyline or polygon, which are represented as finite sequences of coordinate pairs. These geometric representations are standardized in data models such as the

Simple Feature Access Model (SFA) (International Electrotechnical Commission (ISO/IEC) 2004).

But spatial information in narratives tends to not provide the exact coordinates necessary to store the information in geospatial databases. Instead, narratives rely much more on often less precise *qualitative* spatial relations such as “contains”, “near”, “on”, “next to”, “at the corner of”, or “south of” without precise geometric interpretations. Many different types of qualitative spatial relations can be distinguished based on the spatial quality they encode. For example, topological relations, which are amongst the most widely studied qualitative relations, capture only whether two objects are in contact (i.e. connected) or not (i.e. disconnected). Mereological relations (from the greek word μερος for `part’) describe notions of parthood (Simons 1987) such as one object being a proper part of the other, neither being a part of the other but sharing a common part (partial overlap), or them not sharing any part at all. By combining relations about different qualities more expressive relations can be defined. For example, from the combination of topological and mereological relations arise additional *mereotopological* relations (Casati and Varzi 1999; Cohn and Varzi 2003; Hahmann and Grüninger 2012), such as external connection (Clarke 1981; Randell, Cui, and Cohn 1992) or superficial contact (Hahmann and Grüninger 2011), which describe that two objects are in contact but do not share any parts.

Many GIS and their underlying data representations support using qualitative spatial relations, in particular the mereotopological relations from the Region Connection Calculus (Randell, Cui, and Cohn 1992; Cohn et al. 1997) and the dimension-extended version of the 9-intersection approach (Clementini, Di Felice, and van Oosterom 1993; Egenhofer and Franzosa 1991; Clementini and Di Felice 1995; Clementini and Felice 1996) for retrieving (i.e. *querying*) data. For example, these mereological and topological operations allow retrieving all ghetto buildings *within* Budapest or all train lines that cross (partially or entirely) Budapest. But these operations are implemented on top of coordinate-based data, they are not supported for *storing* qualitative spatial data in the first place (Stephen and Hahmann 2019 (to appear)). This is mostly owed to how the underlying spatial databases store spatial information in the *relational database model* (Codd 1970) using only coordinate-based geometries and not in relational form. In the relational database model, each *type* of object is stored in a table with the rows representing the *instances* of that type and each column a specific named property that instances of the type typically have. Because of the utilized normalization techniques that help avoid redundancies and inconsistencies on the stored data (Kent 1983), each type of relationship is stored in a separate table. In that sense the utilized relational database model is prescriptive and forces data into a specific pattern (Florescu, Levy, and Mendelzon 1998), which works well when storing highly structured information, such as about the properties of many objects of a similar type. For example a structured table of Holocaust victims may contain their name, gender, date of birth, place of birth, citizenship and so on, or a table of ghettos may contain their (point) location, creation and closure date, peak population, etc. Mathematically, these kind of properties are *functions*: each person has one and only one value for specific properties, like date of birth. Other properties may have multiple, but still a limited number of values. For example, a database representation may include two columns (*citizenship* and *citizenship2*) to allow capturing two (but no more) distinct citizenships of a person.

But relational spatial knowledge is different from these kinds of properties in that every object can be related to many other objects via many different relationships. For example, the villages Budakalasz, Dunakeszi, Kistarcsa, and Nagytarcsa are all *near* Budapest. Likewise, the villages Budakalasz and Dunakeszi, but also others villages further away, like, Szentendre and Göd, are all north of Budapest. This demonstrates that a single object can be related to a second object via multiple different relationships: Budakalasz (as well as Dunakeszi) are related via the "near" and "north of" relationships to Budapest. With normalization, each relation would become its own table, leading to a proliferation of tables that makes storing and writing queries over the information much more difficult, as it requires recombining the multiple tables using *join* operations. Moreover, for relational databases the schema, that is, the columns of each table, are chosen during the design phase and changes later on can often lead to lots of maintenance work. Thus, relational databases are ill-equipped to store this kind of *relational spatial knowledge* from natural language sources because of: (1) the wide range of spatial relations used -- which would result in a proliferation of tables; (2) the sparsity with which each relation is used, so that the individual tables would be fairly small and retrieving data would almost always require accessing multiple tables, (3) the reference to unnamed or otherwise underspecified places (and times) is not possible, and (4) data and schema (the semantics of the data) are separated. For example, from the relational tables alone it would not be clear that the relations *within*, *contains*, *partially overlaps*, and *disconnected* are all pairwise disjoint (i.e. no two of these four relations can hold between any two objects) nor could such a constraint be easily imposed in a relational database.

These problems are all addressed by graph-based representations, which have been devised to accommodate this kind of highly irregular, semi-structured relational knowledge (Gyssens et al. 1994; Florescu, Levy, and Mendelzon 1998). They are *descriptive* rather than *prescriptive* and they allow mixing "conceptual knowledge" (about the types of concepts such as classes and relations) and data. They are also much more adaptable -- essentially the schema grows with the database -- and are relational by design. While the idea has been around for some time, they have only gained recently more traction outside computer science with the availability of robust triple stores and other databases like Virtuoso, GraphDB, Allegrograph, and Neo4j. The smallest unit of information at the heart of these databases are *triples*, each represented in the form subject-predicate-object (e.g. "Dunakeszi near Budapest" or "Dunakeszi northOf Budapest"), where the subject and object are entities (named or not) that typically correspond to nouns in natural language, and the predicate is a verb or adjective relating the two nouns. For example, we can express that Magda's perwar home was located on Nefelejcs utca using the triple *'h:MadgaMezeiPrewarHome h:onStreet h:"Nefelejcs utca"*.' In this case, *h:MagdaMezeiPrewarHome* and *h:"Nefelejcs utca"* are two named entities, both denoting specific instances of a location. Here, the first location is presumably an apartment (or building) and the second location a street. The are related by the *h:onStreet* relationships, which presumably relates some location to a street location. This fact can be stated by adding more semantic (here: schematic) information, such as 'h:onStreet rdf:range h:street' to express that the object of any h:onStreet relation must be of type h:street. For simplicity, these semantic constraints are largely omitted from our example representation, except for a few typing constraints such as 'h:MagdaMezeiRelocation1 rdf:type h:forcedRelocation.' We can add more spatial detail to our example triple to specify that *Nefelejcs utca* is in Budapest's seventh district by adding additional triples: '*"Nefelejcs utca" inDistrict DistrictSeven.'* and '*"DistrictSeven" inCity Budapest*.' In the formalization, the leading “h:” for each entity and relation denotes that these are new entities and relations that we define and characterize in our sample namespace “h”. While some of the entities, such as *h:MadgaMezeiPrewarHome* are uniquely new entities, others may refer to entities we already know more about, for example ‘h:Budapest’ could potentially be mapped to other references to the city of Budapest, such as DBpedia’s (Lehmann et al. 2015) entity http://dbpedia.org/resource/Budapest, though care must be executed as entities change over time and DBPedia’s entity refers to present-day Budapest which may be conceptually and spatially different from Magda’s Budapest in WWII.

In the following two sections, we draw on the two key themes of trajectories and spatially zooming in and out within a narrative that we highlighted earlier to demonstrate how we might represent spatial information within survivor narratives in triple form.

Trajectories

Trajectories of movements -- both forced and voluntary -- are one of the most obvious and critical spatial aspects of Holocaust victims’ experiences during the war. At the most general level, a spatio-temporal trajectory can be seen as a sequence of individual movements (“episodes”), interrupted by stops (Yan et al. 2010; Yingjie Hu et al. 2013). Each movement is a change in location and each stop is identified with some spatial location such as a house, a town, a ghetto, or a camp, or even less specific places like a “large field”. Magda Mezei, for example, mentions several relocations and other movements. She and her family were forced to move from their pre-war home to the yellow-star house that made up the first form of ghetto implemented in Budapest in 1944 (Cole 2003). Later on, she was forced to march to Zugló on the outskirts of the city with all the women of working age in her building and neighboring houses, but subsequently escaped and returned to the yellow-star house. But other much more temporary movements of importance can also be modeled as trajectories: for example Magda’s two walks to the Spanish Legation (the Spanish embassy) where she obtained protective papers that later meant the family could move into a Spanish-protected building within the so-called ‘International ghetto’ on Szent István Park (Cole 2016).

In a traditional database representation of these movements, locations and times would need to conform to specific datatypes, such as a point location encoded as a coordinate pair, or a timestamp or a precise date for the temporal information. However, this goes counter the information provided by interviewees: they do not always memorize or mention exact addresses, dates or times or even the names of towns. This level or lack of detail should be captured faithfully in the data representation to better understand the victims’ experiences and sense of disorientation. In some cases -- such as the Spanish Legation building that Magda explicitly states she only knew existed because of the help of an acquaintance who took her there -- the lack of specific knowledge is highly significant. Likewise, the data representation should reflect the different temporal and spatial resolutions used by interviewees. In a triple-based graph representation, we can accomplish this by modeling places (e.g. Magda’s pre-war home, the Yellow-Star House, or the field in Zuglo) and times as structured entities, to which more information can be attached as necessary via additional relations, rather than places and times just being values of a property. Furthermore, we can include semantic (i.e. schematic) information in the graph via the *subClassOf* and *subPropertyOf* relations offered by RDF Schema (RDF-S) (Brickley and Guha 2014). For example, we can specific types of places, such as cities, districts, different types of camps, and different types of houses (yellow-star vs. protected houses), as well as types of movements to distinguish between forced relocations (into a ghetto or deportations to camps) and quasi-voluntary relocations (i.e. going into hiding, trying to cross the border into neutral countries like Switzerland) and other, more temporary types of movements.

Consider the example of Magda's forced move to the first ghetto house that she called the 'Star of David house' because it was marked with a large yellow star (in fact, she later refers to it also as the 'Yellow Star House'). She gives some details: the house was on King Street (Király utca), not far from her former home and in the same district (the seventh district), and they moved there in June 1944. We can represent all this information by introducing a unique movement *instance* of the type *forced relocation*: We may call it MagdaMezeiRelocation1 though the name only (uniquely) identifies this specific movement and should not encode any information that is not captured otherwise. Details for this movement instance can then be filled in by adding additional triples that express spatial, temporal and other contextual information, such as who was moved with her (her family including her mother and her brother but not her father), the perpetrators who enforced this upon the family, or the mode of movement.

Unlike in a traditional database format, multiple pieces of information that add spatial and temporal context can be provided. Additionally, the spatial and temporal information can be represented using different granularities to accommodate the variety of specificity found in victims' narratives: for example we can attach one or multiple pieces of information, such as the exact address, just a street name, district number, or city name or even an unnamed placed ("a field"). We can even represent information such as "near X" or at the corner of "Y" which is purely relational information. Thus, there is no need to designate a coordinate-based origin or destination for each movement. For example, when Magda was marched to Zugló, she does not know any details as she was unfamiliar with the area. She just mentions that it was on the outskirts of the city. Here we can still record the location and spatial relations of the place she was taken to as Zugló, a part of Budapest.

Parthood Relations for Zooming In and Out

This is an example of the other characteristic that we identified in victims narratives: that they frequently switch between different spatial and temporal scales. Magda, for example, remembers quite clearly her pre-war home, its street, and the neighborhood, and can precisely describe its location, such as a specific street corner. However, when she is forced to move to other, less familiar parts of town, she "zooms" out and just talks about it being somewhere in the same district ("not far") and, later, in the case of being marched to Zugló as being somewhere in Budapest. This placing of herself in an unknown location within the scale of the city, rather than a more specific and known location, is perhaps most clearly seen in the case of the Spanish Legation. She confesses to her interviewer that she does not know where the Spanish Legation was, and that she only managed to get there with the help of a professor she knew and met on the street (see example instance *h:MagdaMezeiSpanishLegation1*). In this case, we only record the information that the Spanish Legation is *located in* Budapest. It becomes a place recorded in the database - which is vital given its importance in her story of survival - but is recorded there with the level of uncertainty that it receives within Magda's narrative. These various parthood relations structure space hierarchically and allow for recording the zooming in and out that occurs in narratives.

Example Data Representation

The following shows a set of example triples for capturing trajectory and parthood information. Note that triples usually end with a period, though multiple triples with an identical subject can be chained via a semicolon, for example,
'h:MagdaMezeiRelocation1 rdf:type h:forcedRelocation;
h:origin h:MagdaMezeiPrewarHome.' denotes two triples both with *h:MagdaMezeiRelocation1* as subject.

Kinds of movements (movements and relocations are *types* of relations):

h:Relocation rdfs:SubPropertyOf h:Movement.
h:forcedRelocation rdfs:SubPropertyOf h:Relocation.
h:voluntaryRelocation rdfs:SubPropertyOf h:Relocation.

Instances of movement relations:

h:MagdaMezeiRelocation1 rdf:type h:forcedRelocation;
h:origin h:MagdaMezeiPrewarHome;
h:destination h:MagdaMezeiYellowStarHouse;
h:time h:MadgaMezeiRelocationToYellowStarHouseTime;
h:peopleMoved h:MagdaMezeiFamily2.
h:MagdaMezeiSpanishLegation1 rdf:type h:Movement;
h:peopleMoved h:MagdaMezei;
h:peopleMoved h:Professor1;
h:origin h:MagdaMezeiYellowStarHouse;
h:destination h:SpanishLegationBudapest.

Instances of groups of people:

h:MagdaMezei h:partOf h:MagdaMezeiFamily2.
h:MagdaMezei h:givenName "Magda".
h:MagdaMezei h:surname "Mezei".
h:MagdaMezeiMother h:partOf h:MagdaMezeiFamily2.
h:magdaMezeiMother h:motherOf h:MagdaMezei.
h:MagdaMezeiFather h:NotPartOf h:MagdaMezeiFamily2.
h:magdaMezeiFather h:fatherOf h:MagdaMezei.
h:MagdaMezeiBrother h:partOf h:MagdaMezeiFamily2.
h:MagdaMezeiBrother h:brotherOf h:MagdaMezei.
h:MagdaMezeiBrother h:givenName "George".
h:Professor1 h:gender h:Male;
h:occupation "professor";
h:age "55"';
h:acquaintance h:MagdaMezei.

Specification of the places:

h:inCity rdfs:SubPropertyOf h:partOf.
h:inDistrict rdfs:SubPropertyOf h:partOf.
h:onStreet rdfs:SubPropertyOf h:partOf.

h:MadgaMezeiPrewarHome h:onStreet h:“Nefelejcs utca”.
h:“Nefejets utca” h:inDistrict h:DistrictSeven.
h:”DistrictSeven” h:inCity h:Budapest.
h:”Zugló” h:inCity h:Budapest.
h:”Budapest” h:inCountry h:Hungary.
h:MagdaMezeiYellowStarHouse h:onStreet h:“KingStreet”.
h:MagdaMezeiYellowStarHouse h:onStreet h:“Kiraly utca”.
h:MagdaMezeiYellowStarHouse h:inDistrict h:DistrictSeven.
h:SpanishLegationBudapest h:inCity h:Budapest.

Specification of the time:

h:MadgaMezeiRelocationToYellowStarHouseTime rdf:type h:Time;
h:duringMonth June;
h:duringYear 1944.

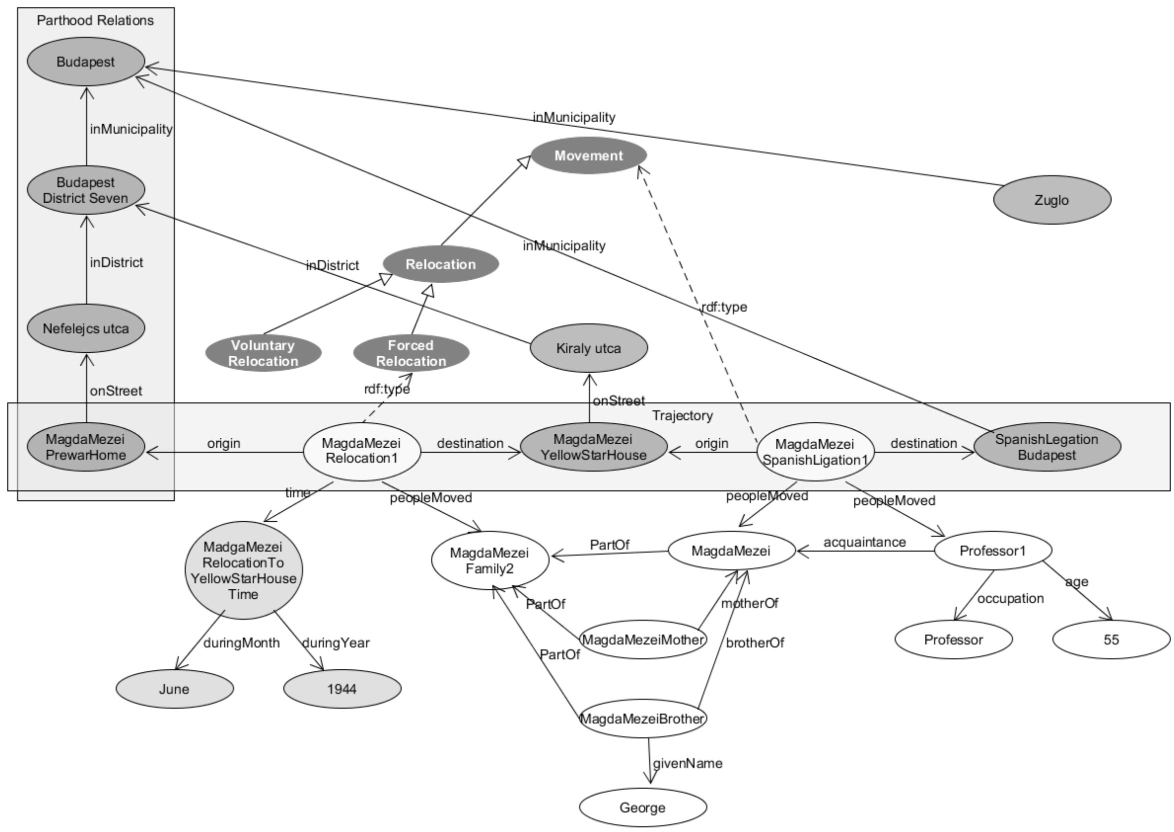

Figure 1: Example triples as a knowledge graph. Horizontally across the two sample movements are shown. On the left side, different parthood relations that can be used to zoom between spatial entities are shown, though the subPropertyOf relationships between the parthood relations are not shown.
Types (i.e. classes) are displayed in white text on dark gray nodes; all other entities are instances. Locations are shown in a darker shade, times in a lighter shade and all other instance entities in white.

Conclusions

In this brief article we reflect on the potential of using triple-based graph representation to work with, rather than against, both the narrative structure and different levels of certainty and uncertainty of survivor testimony. Alongside the possibility of zooming in and out of the scales of narratives, the use of a graph representation allows for the inclusion of the varying degrees of certainty and uncertainty found within humanities sources - most strikingly the memory sources of oral history interviews that we explore here through a case study of a part of Magda Mezei's post-war interview - in the database. In rethinking digital humanities scholarship and the representations of space and place, we argue that there is a need to rethink the underlying logic that lies behind database design. It is here that an approach like QSR is of value in drawing us back to first principles. But it is not simply the case that rethinking database design enables us to work with the complexity of the kind of narratives that digital humanists encounter. They also enable use to undertake new forms of analysis from this complex data. For example, this structure facilitates more comprehensive, aggregate studies of victims' narratives at different scales. It would be easy to retrieve all movements that happened inside (or originated from) Budapest, a specific district therein or a specific street or building, or to take a much broader country-level look at everything in Hungary. This would enable us to ask broader questions of diverse oral history narratives about who moved where, when, and with who. As the example of Magda suggests, there is a need to ask how far relocation was both experienced - and narrated (Knowles, Jaskot, Cole & Giordano 2020 forthcoming) - as solitary or collective experience and to explore who those collectives were and how stable they remained over the course of the genocide. Representing a fragment of Magda's trajectory using triple-based graph representation points to how her experience of the Holocaust was not simply spatial, but was socio-spatial and melded people and place in shifting and complex ways.

Bibliography

Barnes, Trevor J. (2015) "'Desk Killers": Walter Christaller, Central Place Theory, and the Nazis,' in Peter Meusburger, Derek Gregory and Laura Suarsana (eds.), *Geographies of Knowledge and Power*. Heidelberg: Springer Dordrecht; 187-202.

Barnes, Trevor J., and Claudio Minca (2013) "Nazi Spatial Theory: The Dark Geographies of Carl Schmitt and Walter Christaller." *Annals of the Association of American Geographers* 103, 3; 669-87.

Bassin, Mark (1987) "Race Contra Space: The Conflict between German Geopolitik and National Socialism." *Political Geography* 6, 2; 115-34

Beorn, Waitman et. al. (2009) "Geographies of the Holocaust." *Geographical Review* 99, 4; 563-74

Brickley, D., and R. V. Guha. 2014. "RDF Schema 1.1." February 25, 2014. https://www.w3.org/TR/rdf-schema/.

Casati, Roberto, and Achille C. Varzi. 1999. *Parts and Places*. MIT Press.

Charlesworth, Andrew (2004) "The Topography of Genocide," in Dan Stone (ed.), *The Historiography of the Holocaust*. Houndmills: Palgrave Macmillan; 216-52

Clarke, Bowman. 1981. "A Calculus of Individuals Based on `connection'." *Notre Dame Journal of Formal Logic* 22 (3): 204–18.

Clarke, David, Marcus Doel, and Francis McDonough (1996) "Holocaust Topologies: Singularity, Politics, Space." *Political Geography* 15, 6-7; 475-89

Clementini, Eliseo, and Paolino Di Felice. 1995. "A Comparison of Methods for Representing Topological Relationships." *Information Sciences* 3 (3): 149–78.

Clementini, Eliseo, Paolino Di Felice, and Peter van Oosterom. 1993. “A Small Set of Formal Topological Relationships Suitable for End User Interaction.” In *Symp. on Large Spatial Databases (SSD’93)*, 277–95. LNCS 692. Springer.

Clementini, Eliseo, and Paolino Di Felice. 1996. “A Model for Representing Topological Relationships between Complex Geometric Features in Spatial Databases.” *Information Sciences* 90 (1): 121–36.

Codd, E. F. 1970. “A Relational Model of Data for Large Shared Data Banks.” *Communications of the ACM* 13 (6): 377–87.

Cohn, Anthony G., Brandon Bennett, John M. Gooday, and Nicholas M. Gotts. 1997. “Qualitative Spatial Representation and Reasoning with the Region Connection Calculus.” *GeoInformatica* 1: 275–316.

Cohn, Anthony G., and Achille C. Varzi. 2003. “Mereotopological Connection.” *Journal of Symbolic Logic* 32 (4): 357–90.

Cole, Tim, and Graham Smith (1995) “Ghettoization and the Holocaust: Budapest, 1944.” *Journal of Historical Geography* 21, 3; 300-16

Cole, Tim (2003) *Holocaust City. The Making of a Jewish Ghetto*. New York: Routledge

Cole, Tim (2016) *Holocaust Landscapes*. London: Bloomsbury

Cole, Tim (2020 forthcoming) “Geographies of the Holocaust,” in Simone Gigliotti and Hilary Earl (eds.), *The Wiley Companion to the Holocaust*. New York: Wiley.

Cole, Tim, and Alberto Giordano (2014) “Rethinking Segregation in the Ghetto: Invisible Walls and Social Networks in the Dispersed Ghetto in Budapest, 1944,” in Hilary Earl and Karl A. Schleunes (eds.), *Lessons and Legacies XI: Expanding Perspectives on the Holocaust in a Changing World*. Evanston: Northwestern University Press; 265-91

Egenhofer, Max J., and Robert D. Franzosa. 1991. “Point-Set Topological Spatial Relations.” *International Journal of Geographical Information Science: IJGIS* 5 (2): 161–74.

Florescu, Daniela, Alon Y. Levy, and Alberto O. Mendelzon. 1998. “Database Techniques for the World-Wide Web: A Survey.” *SIGMOD Record* 27 (3): 59–74.

Giaccaria, Paolo, and Claudio Minca (2011a) “Topographies/Topologies of the Camp: Auschwitz as a Spatial Threshold.” *Political Geography* 30, 1; 3-12

Giaccaria, Paolo, and Claudio Minca (2011b) “Nazi Biopolitics and the Dark Geographies of the Selva.” *Journal of Genocide Research* 13, 1-2; 67-84

Giaccaria, Paolo, and Claudio Minca (2016) eds., *Hitler’s Geographies: The Spatialities of the Third Reich*. Chicago: University of Chicago Press

Gigliotti, Simone (2009) *The Train Journey: Transit, Captivity, and Witnessing in the Holocaust.* Oxford: Berghahn.

Giordano, Alberto, and Tim Cole (2011) “On Place and Space: Calculating Social and Spatial Networks in the Budapest Ghetto.” *Transactions in GIS* 15, 1; 143-70.

Giordano, Alberto, and Tim Cole (2018) “The Limits of GIS: Towards a GIS of Place.” *Transactions in GIS* 22; 664-676.

Giordano, Alberto, and Tim Cole (2019 forthcoming) “Places of the Holocaust: Towards a Model of a GIS of Place,” *Transactions in GIS*.

Gyssens, Marc, Jan Paredaens, Jan Van den Bussche, and Dirk Van Gucht. 1994. “A Graph-Oriented Object Database Model.” *IEEE Transactions on Knowledge and Data Engineering*, no. 4: 572–86.

Hahmann, Torsten, and Michael Grüninger. 2011. “A Naïve Theory of Dimension for Qualitative Spatial Relations.” In *Symp. on Logical Formalizations of Commonsense Reasoning (CommonSense 2011)*. AAAI Press.

———. 2012. “Region-Based Theories of Space: Mereotopology and Beyond.” In *Qualitative Spatio-Temporal Representation and Reasoning: Trends and Future Directions*, edited by Shyamanta M. Hazarika, 1–62. IGI.

Herod, Andrew. 2010. *Scale*. New York: Routledge.

Hu, Yingjie, Krzysztof Janowicz, David Carral, Simon Scheider, Werner Kuhn, Gary Berg-Cross, Pascal Hitzler, Mike Dean, and Dave Kolas. 2013. “A Geo-Ontology Design Pattern for Semantic Trajectories.” In *Spatial Information Theory*, 438–56. Springer International Publishing.

Hu, Ying, Siva Ravada, Richard Anderson, and Bhuvan Bamba. 2012. “Topological Relationship Query Processing for Complex Regions in Oracle Spatial.” In *Intern. Conf. on Advances in Geographic Information Systems (SIGSPATIAL 2012)*, 3–12.

International Electrotechnical Commission (ISO/IEC). 2004. “ISO 19125:2004 Geographic Information -- Simple Feature Access.”

Kent, William. 1983. “A Simple Guide to Five Normal Forms in Relational Database Theory.” *Communications of the ACM* 26 (2): 120–25.

Knowles, Anne Kelly, Tim Cole, and Alberto Giordano (2014) eds.,*Geographies of the Holocaust*. Bloomington: Indiana University Press.

Knowles, Anne Kelly, Paul Jaskot, Tim Cole, and Alberto Giordano (forthcoming 2020) “Mind the Gap: Reading across the Holocaust Testimonial Archive,” in Tim Cole and Simone Gigliotti (eds.) *The Holocaust in the 21st Century: Relevance and Challenges in the Digital Age. Lessons and Legacies Volume XIV*. Evanston: Northwestern University Press.

Lehmann, Jens, Robert Isele, Max Jakob, Anja Jentzsch, Dimitris Kontokostas, Pablo N. Mendes, Sebastian Hellmann, et al. 2015. “DBpedia -- A Large-Scale, Multilingual Knowledge Base Extracted from Wikipedia.” *Semantic Web Journal* 6 (2): 167–95.

Obe, Regina O., and Leo S. Hsu. 2015. *PostGIS in Action*. 2nd ed. Manning Publications.

Pollin-Galay, Hannah (2020 forthcoming) “When the Index is Wrong: Exploring Black Holes in Victim Memory” in Tim Cole and Simone Gigliotti (eds.)*The Holocaust in the 21st Century: Relevance and Challenges in the Digital Age. Lessons and Legacies Volume XIV*. Evanston: Northwestern University Press.

Randell, David A., Zhan Cui, and Anthony G. Cohn. 1992. “A Spatial Logic Based on Regions and Connection.” In *KR’92: Principles of Knowledge Representation and Reasoning*, 165–76.

Rössler, Mechtild (1989) ‘Applied Geography and Area Research in Nazi Society: Central Place Theory and Planning, 1933 to 1945,’ *Environment and Planning D: Society and Space* 7, 4; 419-31

Simons, Peter. 1987. *Parts - A Study in Ontology*. Clarendon Press.

Stephen, Shirly, and Torsten Hahmann. 2019 (to appear). “Formal Qualitative Spatial Augmentation of the Simple Feature Access Model.” In *Proc. of the 14th Intern. Conf. on Spatial Information Theory (COSIT 2019)*. Leibniz International Proceedings in Informatics (LIPIcs). Schloss Dagstuhl--Leibniz-Zentrum fuer Informatik.

USHMM (1990). Interview with Magda Mezei Lapidus. 23 August, 1990. RG-50.030*0122

Yan, Zhixian, Christine Parent, Stefano Spaccapietra, and Dipanjan Chakraborty. 2010. “A Hybrid Model and Computing Platform for Spatio-Semantic Trajectories.” In *The Semantic Web: Research and Applications*, 60–75. Springer Berlin Heidelberg.

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